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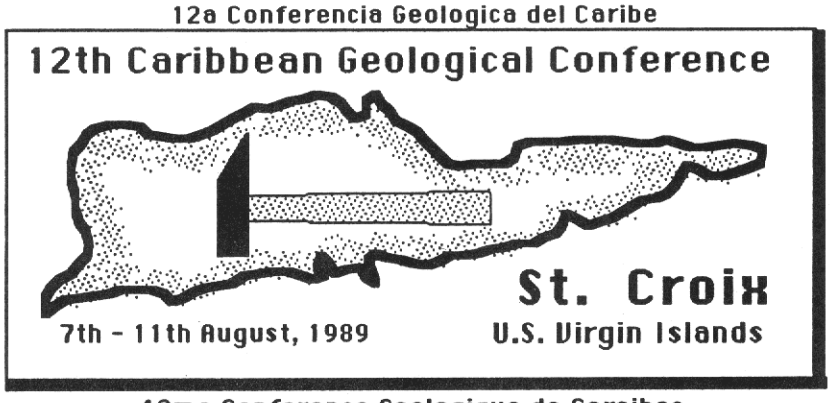

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PATCH REEF ECOLOGY, SEDIMENTOLOGY AND DISTRIBUTION BUCCOO REEF COMPLEX, TOBAGO

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ABSTRACT

Four distinct patch reef types have been identified in the back-reef and lagoonal areas of the Buccoo Reef Complex, Southwestern Tobago. This differentiation is based on ecology, associated sediment distribution, and their geographic location within the reef environment.

Algae - Porites patch reefs are elongate to sub-circular in plan view, and dominated by algal-encrusted Porites coral rubble and Halimeda opuntia, and minor clumps of Porites porites and Thalassia testinidium. Elongate-shaped Acropora patch reefs are composed of thickets of Acropora cervicornis, with minor stands of A. prolifera and species of Siderastrea, Agaricia, Montastrea and Diploria. Acropora-Millepora assemblages which are elongate to sub-elliptical in shape, are compositionally similar to the Acropora assemblages, except for the introduction of extensive occurrences of the hydrozoan Millepora. A single occurrence of the elongate to tabular-shaped Montastrea assemblage is predominated by coral heads of Montastrea annularis.

Extensively fragmented Halimeda plates are the dominant sediment particles associated with Algae - Porites patch reefs. Particles of coral, coralline - algae, Halimeda, and mollusc grains in varying percentages, occur on the substrates of the Acropora and Acropora - Millepora assemblages.

A systematic change, relative to their distinctive ecology, occurs in the distribution of patch reefs in the lagoonal and back-reef areas of the reef complex. This geographic distribution and specific ecological characteristics are primarily controlled by the degree of wave exposure, and are moderately influenced by water circulation and turbidity.

INTRODUCTION

Physical Setting

The island of Tobago is situated in the southeastern Caribbean, near the junction of the Lesser Antillean outer sedimentary arc or accretionary prism to the northeast, the Atlantic Basin to the southeast, and the South American Mainland to the southwest (Case, 1975, Mascle et al., 1979). It is located at approximately 11°N latitude and 61°W longitude, 32.2 km northeast of Trinidad. Covering an area of 301 km², the island is 42 km long and 12 km wide at its widest point.

The Buccoo Reef Complex and its associated environs are situated in the southwest corner of the island of Tobago (Fig. 1). Encompassing an area of approximately 7 km², the coralgal reef forms a broad arc around the lagoonal area. It is composed of 5 discontinuous reef flats, with numerous patch reefs in the back-reef and lagoonal areas (Fig. 1). From west to east, the reef flats are named Pigeon Point, Western, Northern, Outer and Eastern (Kenny, 1976). The Reef Lagoon, Inner and Outer Bon Accord Lagoons are enclosed by these reefs flats.

Average depths of 2 - 5 m in the Reef Lagoon, and 2 - 4 m in Inner and Outer Bon Accord Lagoons with a few deep depressions were observed. Surface currents exhibited simple circulatory patterns of low to moderate strength (2 to 6 cm/s), controlled chiefly by the Antillean current, prevailing Northeast Trade Winds and tidal variations (Kenny, 1976).

Purpose of Study

The patch reefs or coral-rich areas in the back-reef and lagoonal areas of Buccoo Reef Complex have not been previously described in any detail (Kenny, 1976). In order to provide scientific data on this component of the Buccoo Reef System, this study was carried out:

(1) To describe patch reefs of the reef complex, with special emphasis on their stage(s) of development.
(2) To determine the nature of patch reef sediments.
(3) To explain the geographic distribution of the patch reefs in the back-reef and lagoonal environments of the reef system.

Methodology

During a marine geological survey of the Buccoo Reef Complex in June-August, 1980, dissimilar patch reefs were mapped in detail along north-south traverses at 10 m intervals(Fig. 1), and 31 other reefs were studies in general. These field observations were supplemented by aerial photographic analyses, where the colour contrasts on the photographs were utilized for defining the boundaries of patch reefs at that time.

PATCH REEF ENVIRONMENTS

Ecology

Four different patch reefs were identified in the lagoonal and back-reef areas of the Buccoo Reef Complex (Fig. 1). They are as follows:

1. Algae - Porites;
2. Acropora;
3. Acropora-Millepora;
4. Montastrea.

Thirty-four patch reefs were mapped and located. Of these, 17 were Algae - Porites, 13 were Acropora, 3

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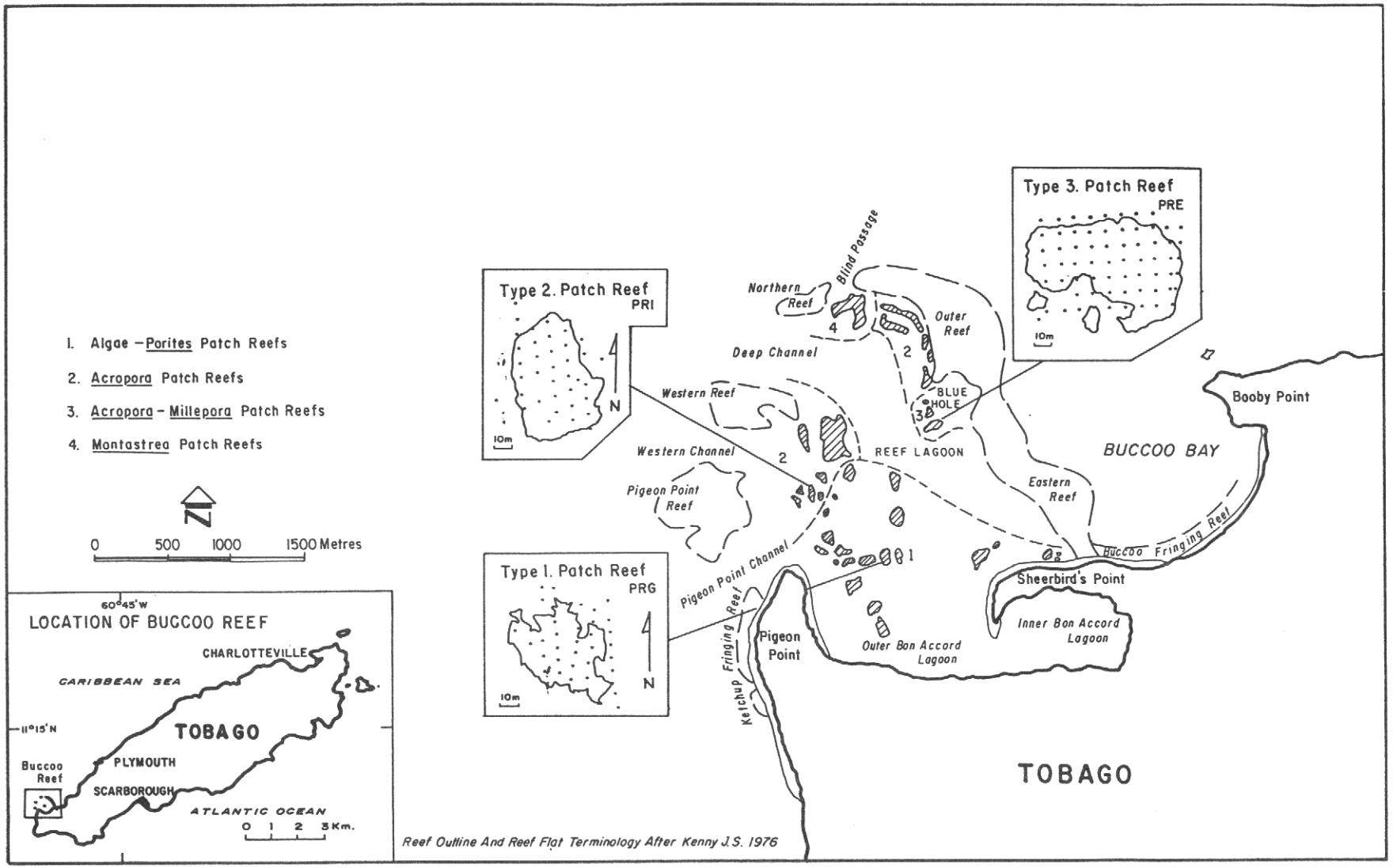


Fig. 1 - Map of Buccoo Reef Complex showing distribution of various patch reefs. Inset maps indicate patch reefs studied in detail and location of Buccoo Reef.

were Acropora - Millepora, and 1 of the Montastrea variety (Fig. 1).

Algae - Porites Patch Reefs

Algae - Porites patch reefs are located in the south-central areas of Reef Lagoon, and south-western portions of Outer Bon Accord Lagoon (Fig. 1). They are elongate to sub-circular in shape, forming shallow, rather subdued mounds which rise from depths of 2 - 5 m in lagoonal areas, to less than 0.5 m below sea level in some cases. These mounds range in size from 50 to 5000 m^2.

For a more detailed examination of these organism-rich areas, a patch reef located on the northern margin of Outer Bon Accord Lagoon, approximately 500 m to the west of Pigeon Point was chosen as a typical example (Fig. 1). Referred to as Patch Reef Giselle (PRG), it is approximately 4000 m^2 in area, and rises from depths of 2 - 3 m in surrounding lagoonal waters to approximately 0.5 - 1 m in its north-central portion (Fig. 2A).

Ecologically, living corals are very sparse (5%) and confined to small clumps of Porites porites (Fig. 2B). Porites coral rubble and extensive H. opuntia are the predominant constituents on the substrate of this patch reef (Figs. 3A and 3B). Porites coral and coral rubble are both heavily encrusted by Halimeda spp., coralline-red algae, boring molluscs and serpulid tubes. Growth of Halimeda spp. on sand substrates occurs towards the margin of the patch reef. Minor occurrences of Thalassia testinidum and burrow mounds are also present. Living organisms, e.g. molluscs, brittle stars, sea anemones, sponges, and sea urchins, are associated with the coral rubble.

The percentage of living Porites coral increases to about 20% in the Algae - Porites patch reefs located in the Reef Lagoon. Minor sea fans and sea whips are also present.

Acropora Patch Reefs

Acropora patch reefs are located in southwestern and northeastern Reef Lagoon; to the east of Pigeon Point and Western reef flats, and bordering the Outer Reef Flat respectively (Fig. 1). The reefs are elongate to tabular in shape. These patch reefs form coral-rich banks which are approximately at 1 m elevation above the lagoon floor towards their centre. They range in area from 50 to 60,000 m^2, and are subaerially exposed during extreme spring tidal lows.

Patch Reef Ivy (PRI) was selected as a typical example of these Acropora - rich areas (Fig. 1). PRI is located approximately 400 m north of Pigeon Point peninsula and 350 m west of Pigeon Point Reef Flat. It is approximately 4500 m^2 in area, and rises to within 1 m of sea level on its south and southeastern sections (Fig. 4A).

Living corals average about 30 - 40% on Patch Reef Ivy, and are dominated by thickets of Acropora cervicornis (Fig. 4B). Patch reef stabilization is achieved by the interlocking, growth framework of the branching Acropora colonies. Minor patches of diverse coral species of Siderastrea, Agaricia, Montastrea and Diploria, and the hydrozoan Millepora are also present. Easily fragmented A. cervicornis accounts for an extensive coral rubble (Fig. 5A) which is moderately encrusted by coralline-red algae. Halimeda sp. growth occurs at the base of dead coral branches (Fig. 5B). Minor occurrences include sea fans, sea whips, molluscs, sponges and the conch Strombus gigas. Burrow mounds on bare sand areas are also present.

Acropora - Millepora Patch Reefs

Acropora - Millepora patch reefs are located in the eastern portion of Reef Lagoon bordering the Blue (Deep) Hole (Fig. 1). They are elongate to sub-elliptical in shape and form coral-rich banks similar in appearance to the Acropora patch reefs. The Acropora - Millepora patch reefs rise from lagoonal depths of 2 m to less than 1 m below sea level toward their centres. They range in area from 600 to 6000 m^2.

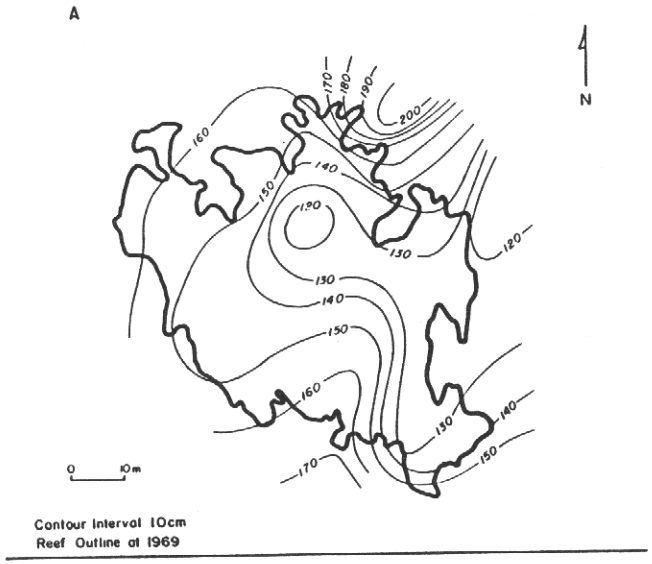
Patch Reef Elsa (PRE) represented a typical example of the Acropora - Millepora coral-rich areas (Fig. 1). It is located on the western margin of the Blue (Deep) Hole, and is approximately 6000 m^2 in area. It rises to within 1 m of sea level (Fig. 6A).

The hydrozoan Millepora along with living coral species dominated by A. cervicornis, cover 10-50% of the substrate of Patch Reef Elsa (Fig. 6B). M. alcicornis with minor occurrences of M. complanata are the main hydrozoan species present. Minor Diplora sp. and Siderastrea sp. also occur on this patch reef. Similar to the Acropora Patch Reef (PRI), patch reef stabilization is achieved on PRE by the interlocking, growth patterns of A. cervicornis. Fragmented coral and Millepora rubble encrusted by Halimeda spp. and coralline-red algae are very abundant (Figs. 7A and 7B). On the southwestern margin of the patch reef, dead coral and Millepora skeletons are extensively overgrown by a green algae. Burrow mounds occur in bare sand areas, and molluscs and sea anemones are also present.

Montastrea Patch Reef

A Montastrea-dominated patch reef is located at the lagoonal entrance of the Blind Passage, on the southern border of the northwestern tip of Outer Reef Flat (Fig. 1). This area, due to its prolific coral growth, is referred to as the Coral Gardens. The patch reef is approximately 9500 m^2 in area and elongate-tabular in shape. Coral growth begins in back-reef areas at depths of 2 m, continuing towards the Reef Lagoon in increasing depths up to 10 m (Kenny, 1976).

The coral-rich area was not examined in detail. The shallower portions of the patch reef (depths of 2 - 4 m) are dominated by coral heads of Montastrea annularis, interspersed with a variety of sea fans, sea whips and the hydrozoans Millepora. Numerous eroded coral heads, probably destroyed by grazing parrot fish and the sea urchin Diadema are also common in this area. At mid-depth (3 - 7 m), scattered M.



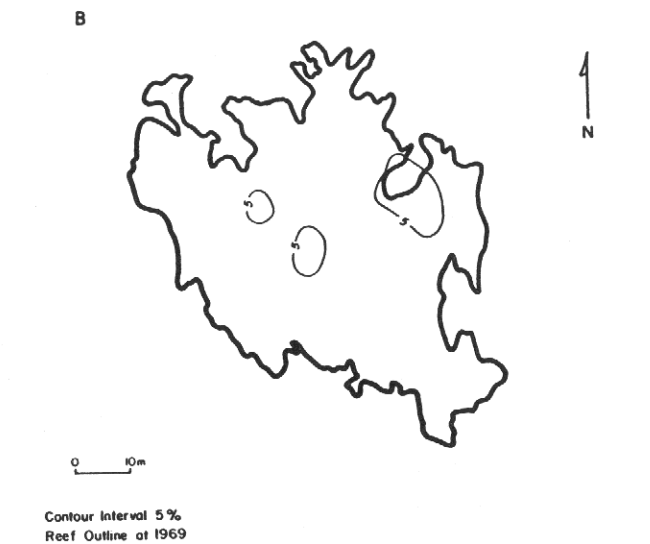
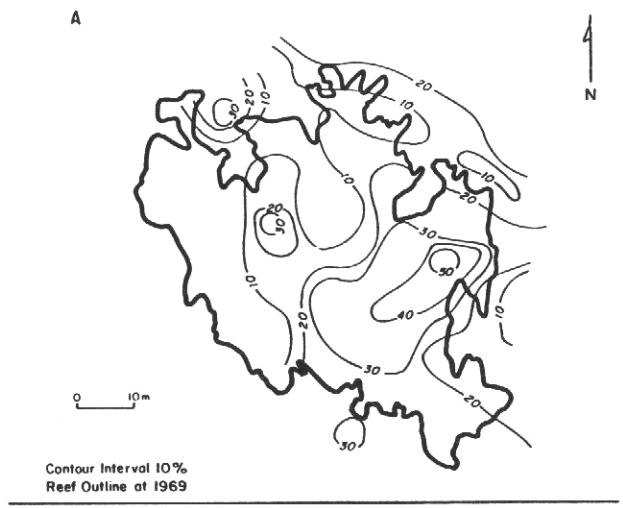


Fig. 2A - Bathymetric map of Patch Reef Giselle, an Algae - Porites Patch Reef

Fig. 2B - Contour map of percentage occurrences of the living coral Porites on Patch Reef Giselle, an Algae - Porites Patch Reef



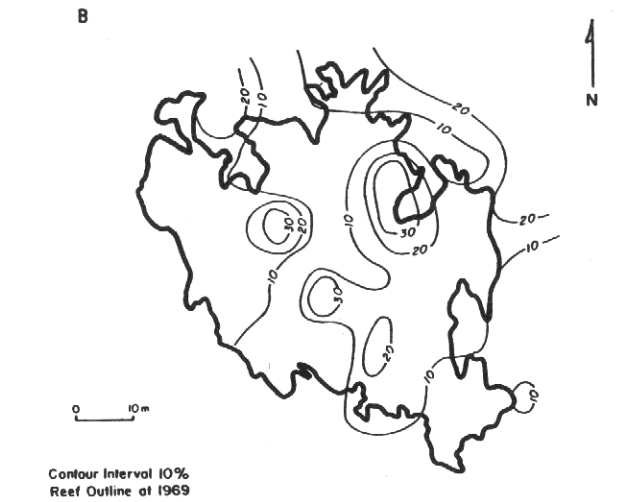
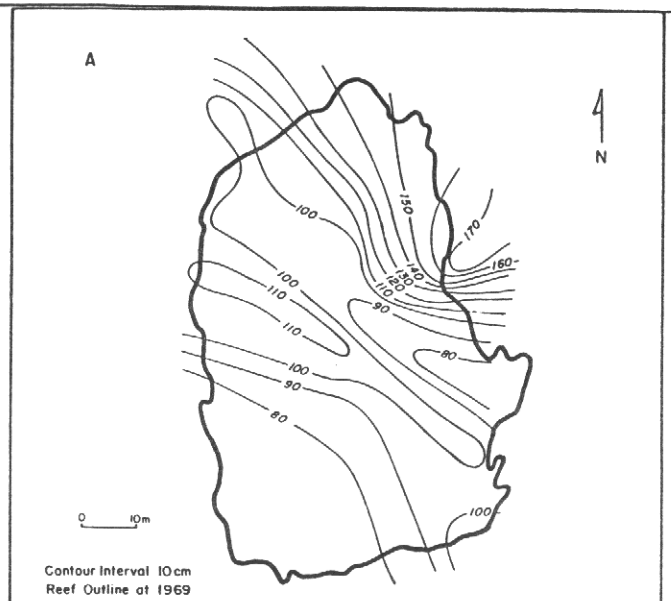


Fig. 3A - Contour map of percentage occurrences of Porites coral rubble on Patch Reef Giselle, an Algae - Porites Patch Reef.

Fig. 3B - Contour map of percentage occurrences of Halimeda on Patch Reef Giselle, an Algae - Porites Patch Reef.



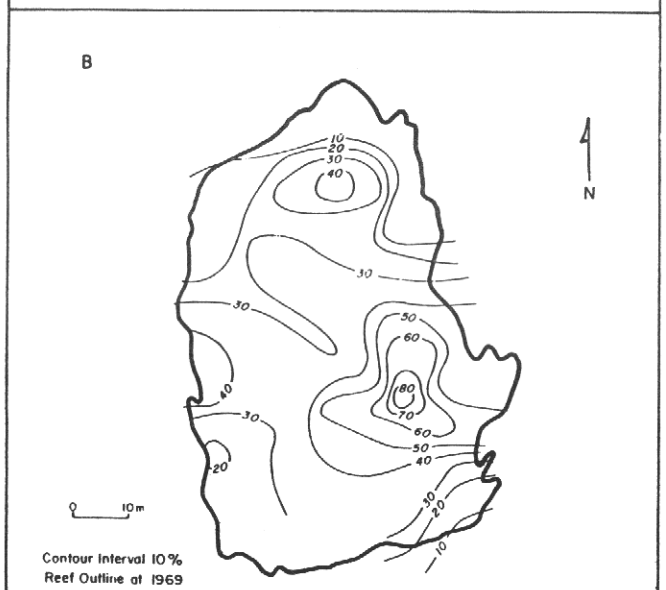
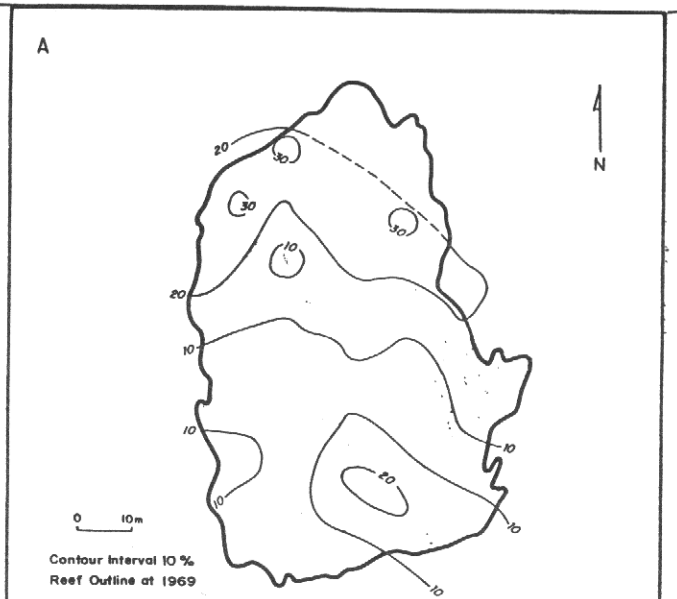


Fig. 4A - Bathmetric map of Patch Reef Ivy, an Acropora Patch Reef.

Fig. 4B - Contour map of percentage occurrences of the living coral Acropora on Patch Reef Ivy, an Acropora Patch Reef.



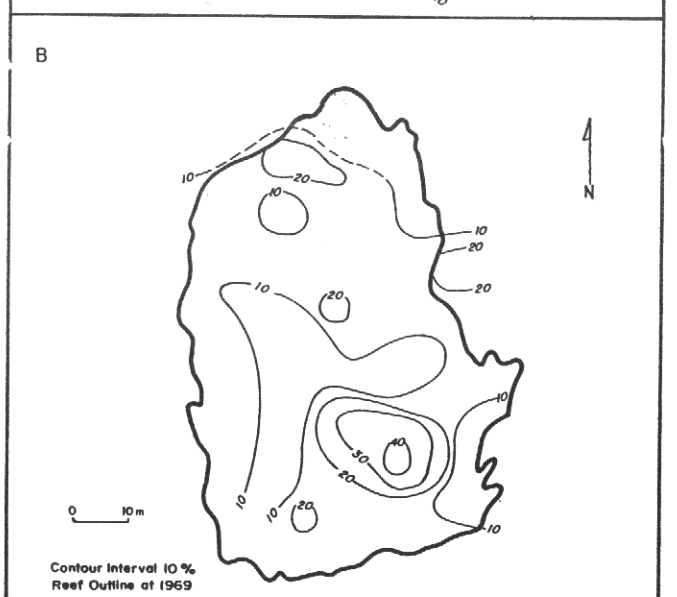


Fig. 5A - Contour map of percentage occurrences of coral rubble on Patch Reef Ivy, an Acropora Patch Reef.

Fig. 5B - Contour map of percentage occurrences of Halimeda on Patch Reef Ivy, an Acropora Patch Reef.

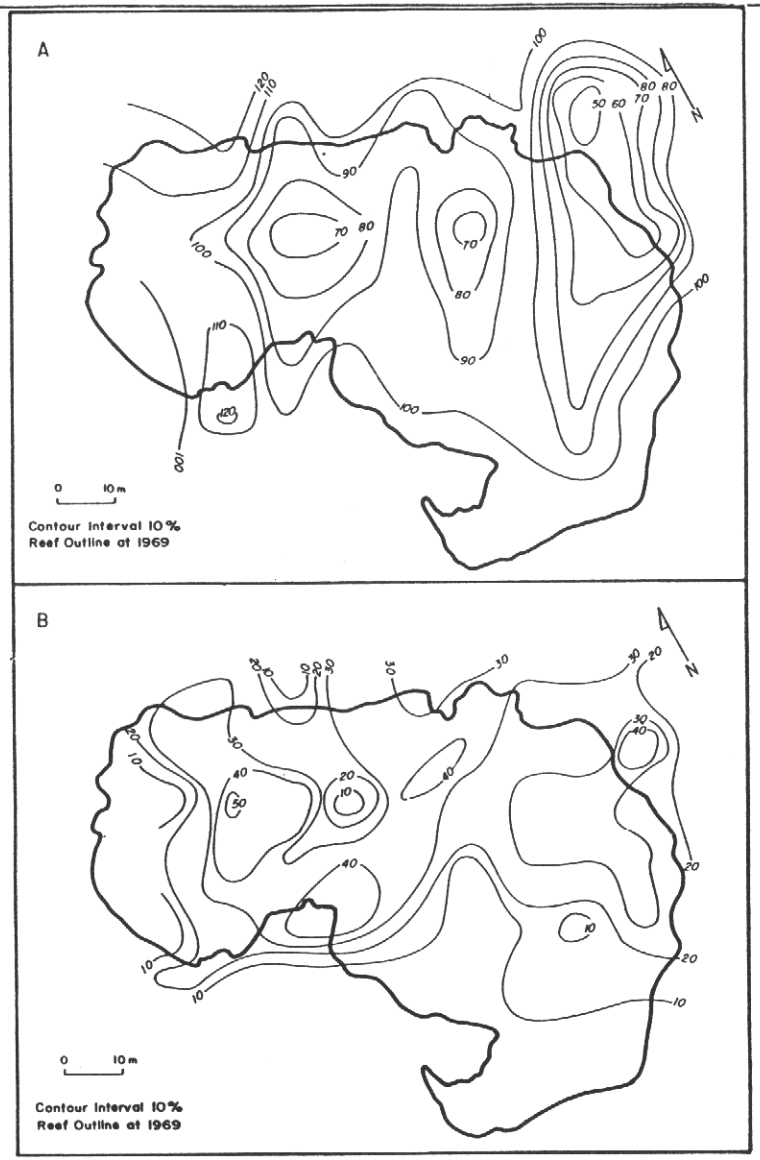


Fig. 6A - Bathymetric map on Patch Reef Elsa, an Acropora - Millepora Patch Reef.

Fig. 6B - Contour map of percentage occurrences of coral and the hydrozoan Millepora on Patch Reef Elsa, an Acropora - Millepora Patch Reef.

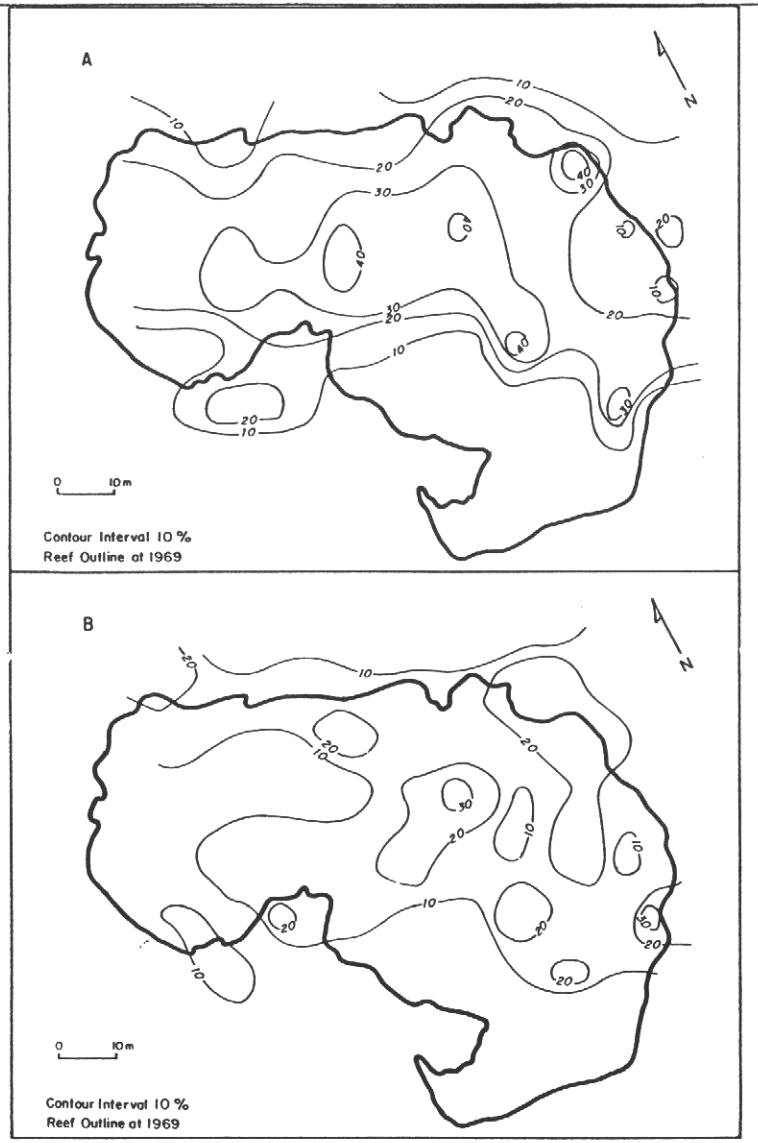


Fig. 7A - Contour map of percentage occurrences of coral (including Millepora) rubble on Patch Reef Elsa, an Acropora - Millepora Patch Reef.

Fig. 7B - Contour map of percentage occurrences of Halimeda on Patch Reef Elsa, an Acropora - Millepora Patch Reef.

annularis are associated with occasional colonies of Acropora palmata, A. cervicornis and Porites astreoides. Coral colonies in the deepest areas (>7m) consist of heads of M. annularis, M. lamarkana, Diploria strigosa, D. labrynthiformis, Colpophyllia natans and Siderastrea sidera (Kenny 1976).

Sediments

Sediments in the Algae - Porites patch reefs are generally composed of Halimeda particles. Minor amounts of coral, coralline-algae and mollusc grains, along with gorgonacea and sponge spicules are also present. Of significance are minor amounts of terrigenous quartz silt in all sediment samples of the Algae - Porites patch reefs (Table 1). Most particles are extensively abraded. These sediments are predominantly of a coarse sand size and poorly to moderately sorted (Table 2).

PATCH REEF	MEAN Ø		SORTING Ø	
Algae - Porites	0.57	Coarse sand	1.64	Poorly sorted
	1.00	Coarse sand	1.27	Poorly sorted
	0.94	Coarse sand	0.79	Moderately sorted
	0.93	Coarse sand	1.37	Poorly sorted
	0.92	Coarse sand	1.21	Poorly sorted
Acropora	1.56	Medium sand	1.23	Poorly sorted
	0.91	Coarse sand	1.81	Poorly sorted
	1.04	Medium sand	1.30	Poorly sorted
	0.99	Coarse sand	1.46	Poorly sorted
	1.64	Medium sand	1.46	Poorly sorted
Acropora - Millepora	1.08	Medium sand	1.05	Poorly sorted
	1.18	Medium sand	1.16	Poorly sorted
	1.32	Medium sand	1.16	Poorly sorted
	1.08	Medium sand	1.17	Poorly sorted
	1.08	Medium sand	1.18	Poorly sorted

Table 2: Grain Size Analysis of Some Representative Samples of Patch Reef Sediments

The Acropora patch reefs are characterized by sediments composed of Halimeda grains, with occurrences of coral, coralline - algae and mollusc fragments, which are in a greater abundance compared to the sediments of the Algae-Porites patch reefs (Table 1). These patch reef sediments are not excessively fragmented, and several particles are encrusted by worm tubes, benthonic foraminifera, and coralline algae. The sediments range in size from medium to coarse sand, and are generally poorly sorted (Table 2).

The sediments of the Acropora - Millepora patch reefs are similar in composition to the Acropora patch reef sediments (Table 1). These sediments are extensively fragmented, and coral grains are well rounded. Some mollusc particles are heavily bored. Sediments are of a medium sand size and poorly sorted (Table 2).

Geographic Distribution

A systematic change in the distribution of patch reef types occurs in the lagoonal areas of the Buccoo Reef Complex. With their distinct ecology and associated communities, this systematic change outlines a general geographic distribution of the patch reefs (Fig. 1). Algae - Porites patch reefs occur in the southern lagoonal areas at south-central Reef Lagoon and western Outer Bon Accord Lagoon. Acropora patch reefs are located in central and northern lagoonal areas, on the south-western and northeastern margins of Reef Lagoon. Acropora - Millepora patch reefs are restricted to central lagoonal areas, bordering the Blue (Deep) Hole. The Montastrea patch reef is confined to the northern lagoonal areas adjacent to the entrances of the Blind Passage and Deep Channel (Fig. 1).

DISCUSSION AND SUMMARY

Table 3 summarizes the major characteristics of the patch reefs in the lagoonal areas of the Buccoo Reef Complex. Similar patch reef communities occur in Watering Bay, Grenada (Pendlebury, unpublished), and Glovers Reef Atoll, Belize (Wallace and Schafersman, 1977).

Reef-Building Framework

The Algae - Porites patch reef form constructive elements, despite their non-rigid framework, owing to the trapping and binding of sediment by Porites coral rubble. The rubble is not cemented to the substrate, but held in place by the intergrowth of green algae Halimeda, a feature observed in the development of the Rodriguez Mudbank (Turmel and Swanson, 1976). In addition, the baffling effect on sediments by the blue-green algae H. opuntia, and marine grass T.testinidum further stabilizes these patch reefs (Multer and Zankl, 1985).

Growth and colonization of Acropora and Acropora - Millepora patch reefs are probably initiated by asexual regeneration of broken A. cervicornis branches. That is, the broken branches healed their ends and started budding. Further stabilization and framework development in these patch reefs are achieved by the fusing of A.cervicornis branches with each other, and with the surrounding substrate (Gilmore and Hall, 1976). In addition, organic cementation by coralline-red algae and benthonic foraminifera contributes to the process of fusion (Multer and Zankl, 1985). Similar to the Algae - Porites patch reefs,

TABLE 1: PERCENTAGE COMPOSITION OF SOME REPRESENTATIVE SAMPLES OF PATCH REEF SEDIMENTS

PATCH REEF	Halimeda	Coral	Coralline - Algae	Molluscs	Benthonic Foraminifera	Echinoid Spines	Spicules	Quartz Silt	Other
	72	6	-	10	-	2	4	5	1
	74	4	2	10	1	1	3	4	1
Algae -	83	3	4	6	-	-	1	2	1
Porites	74	5	1	14	-	-	3	1	2
	69	1	2	16	1	1	4	2	4
	30	12	33	20	-	1	2	1	1
	58	7	13	16	-	-	4	1	1
Acropora	41	27	15	10	1	-	3	1	2
	57	13	15	10	1	-	1	1	2
	55	22	14	5	-	-	2	1	1
	31	36	17	13	1	-	-	<1	2
	53	18	14	8	1	-	3	1	2
Acropora -	53	19	16	8	<1	-	1	1	2
Millepora	39	27	24	8	<1	-	1	<1	<1
	53	10	21	15	1	-	<1	<1	<1

Other grains are mainly pelagic forminifera and worm tubes.

TABLE 3: SUMMARY OF CHARACTERISTICS OF PATCH REEFS IN THE LAGOONAL AREAS OF THE BUCCOO REEF COMPLEX

PATCH REEF TYPES	ALGAE - PORITES	ACROPORA	ACROPORA - MILLEPORA	MONTASTREA
Location	South-central Reef Lagoon; Western Outer Bon Accord Lagoon	Southwestern and Northeastern Reef Lagoon	Eastern Reef Lagoon	Lagoonal entrance of Blind Passage
Shape	Elongate to sub-circular	Elongate to tabular	Elongate to sub-elliptical	Elongate - tabular
Area (m^2)	50 - 5000	50 - 60,000	600 - 6500	4500
Major Communities	Porites coral rubble; Halimeda opuntia	A. cervicornis; Acropora rubble; Halimeda sp.	A. cervicornis; M. alcicornis; Acropora and Millepora skeletons; Halimeda sp.; fleshy green algae	M. annularis
Minor Communities	P. porites; T. testinidium; coralline-red algae; molluscs; sponges; sea urchins	A. prolifera; Siderastrea; Agaricia; Montastrea; Diploria; Millepora; sea fans; sea whips; coralline-red algae	A. prolifera; Diploria; Siderastrea; M. complanata; sea fans; sea whips; coralline-red algae	Millepora sp.; A. palmata; A. cervicornis; P. astreoides; M. lamarkana D. strigosa; D. labrynthiformis; C. natans; S. siderea; M. areolata; E. fastigiata; sea fans; sea whips; sea urchins
No. of Significant Patch Reefs >50 m^2	17	13	3	1

Acropora and Millepora rubble also trap and bind sediment, which contributes to the framework building process.

The interlocking, growth patterns observed on Acropora and Acropora - Millepora patch reefs result from the fusion process of A. cervicornis described above.

The Montastrea Patch Reef forms a rigid framework, built up of coral heads of M. annularis. The ability of M. annularis to exclude almost all other corals competing with it for the same space, by extracoelenteric digestion (polyps of M. annularis extrude mesenterial filaments which dissolve the tissues of other corals), ensures its dominance on this patch reef as the primary reef builder (Lang, 1973; Scatterday, 1977).

Lack of Coral Diversity

The patch reefs of Buccoo Reef Complex generally exhibit a lack of coral diversity (Table 3). This aspect is probably due to the limited depths in which these patch reefs occur (generally 1 - 4 m), inhibiting vertical development and probable ecological zonation.

The weakly defined ecological zones (M. annularis 2 - 4 m; M. annularis, Acropora spp. 3 - 7 m; mixed coral head zone, >7 m) in the Montastrea Patch Reef, have developed because of its occurrence in deeper waters, which allowed for some vertical development. In addition, extensive biological erosion of M. annularis coralla by parrot fish and sea urchins, provides available substrate for other coral species to develop (Frydl, 1977; Scatterday, 1977).

Stages of Development

Based on observations and detailed mapping, four stages of development for patch reefs in the lagoonal areas of the Buccoo Reef Complex can be recognised, using Multer's (1975) model for the evolution of Florida patch reefs (Fig. 8):

(1) An initial stage with incipient development of corals.
(2) A youthful stage exhibiting luxuriant coral growth.
(3) A mature stage which is characterized by decreased coral growth and increased rubble deposits.
(4) An old age stage predominated by coral rubble which is encrusted with coralline and fleshy algae.

The Algae - Porites patch reefs are present in the mature and old age stages. These patch reefs would have been initiated by the incipient development of P. porites on stable sand or bare rock substrate. They would then progress to the youthful stage where P. porites would be dominant with minor occurrences of Porites rubble. Moderate to extensive Porites rubble encrusted by Halimeda and coralline-algae, characterise the mature and old age stages respectively, for Algae - Porites patch reefs observed at present (Fig. 8).

The Acropora patch reefs occur in the incipient, youthful and mature stages of development. The colonization of stable sand substrates by initial growth of A. cervicornis, the incipient stage of Acropora patch reefs, is present as discrete thickets in the Reef Lagoon. The youthful development stage of these patch reefs also occurs in Reef Lagoon as A. cervicornis coral-rich areas with minor Acropora rubble. Breakage of Acropora branches result in the formation of extensive coral rubble encrusted by Halimeda, which define the mature stage of development. The old age stage of Acropora patch reef development, which would probably be dominated by coral rubble with minimal coral growth was not observed (Fig. 8).

Acropora - Millepora patch reefs are restricted to the mature stage of development. The incipient stage of these patch reefs would also be the A. cervicornis thickets from which the Acropora patch reefs evolve. However in certain sections of Buccoo Reef lagoons where medium to high energy wave conditions occur, the hydrozoan Millepora will begin to replace A. cervicornis colonies (Adey and Burke, 1977). Millepora and Acropora communities and associated rubble, encrusted by Halimeda, coralline-red and fleshy green algae are observed, and characterize the mature development stage of Acropora - Millepora patch reefs. The old age stage of extensive Acropora and Millepora rubble encrusted by fleshy algae and probably Palythoa spp. has not yet developed (Fig. 8).

The Montastrea patch reef would have developed by the initiation of Montastrea growth on suitable substrates. This would have been followed by a M. annularis dominated patch reef in its youthful stage. At present, the Montastrea Patch Reef is transitional between the mature and old age stages of development. The dominant M. annularis coral heads exhibit extensive biological erosion, and these bare surfaces and other areas have been colonized by diverse coral species. Dead coral heads and coral rubble are observed in certain areas (Fig. 8).

Sediment Characteristics

Extensive occurrences of H. opuntia on the substrate and encrusting Halimeda spp. on Porites coral rubble (Figs. 3A and 3B) result in the predominance of Halimeda fragments in the sediments of the Algae - Porites patch reefs. In contrast, larger percentages of living corals and hydrozoans, encrusted by various organisms (Figs. 4B, 5A, 5B, 6B, 7A and 7B) result in a more equitable distribution of Halimeda, coral, coralline - algae and mollusc particles in the sediments of the Acropora and Acropora - Millepora patch reefs. Patch reef sediments therefore generally occur in situ. This factor is further supported by their medium to coarse sand size and poorly sorted nature.

The presence of fine size quartz silt in the sediments of the Algae - Porites patch reefs is indicative of a terrigenous input to these areas, through the canals and streams draining into the Inner and Outer Bon Accord Lagoons.

Factors Controlling Patch Reef Occurrences and Development

The geographic zonation of the different patch reefs in the lagoonal areas, their distinct ecological characteristics and various stages of

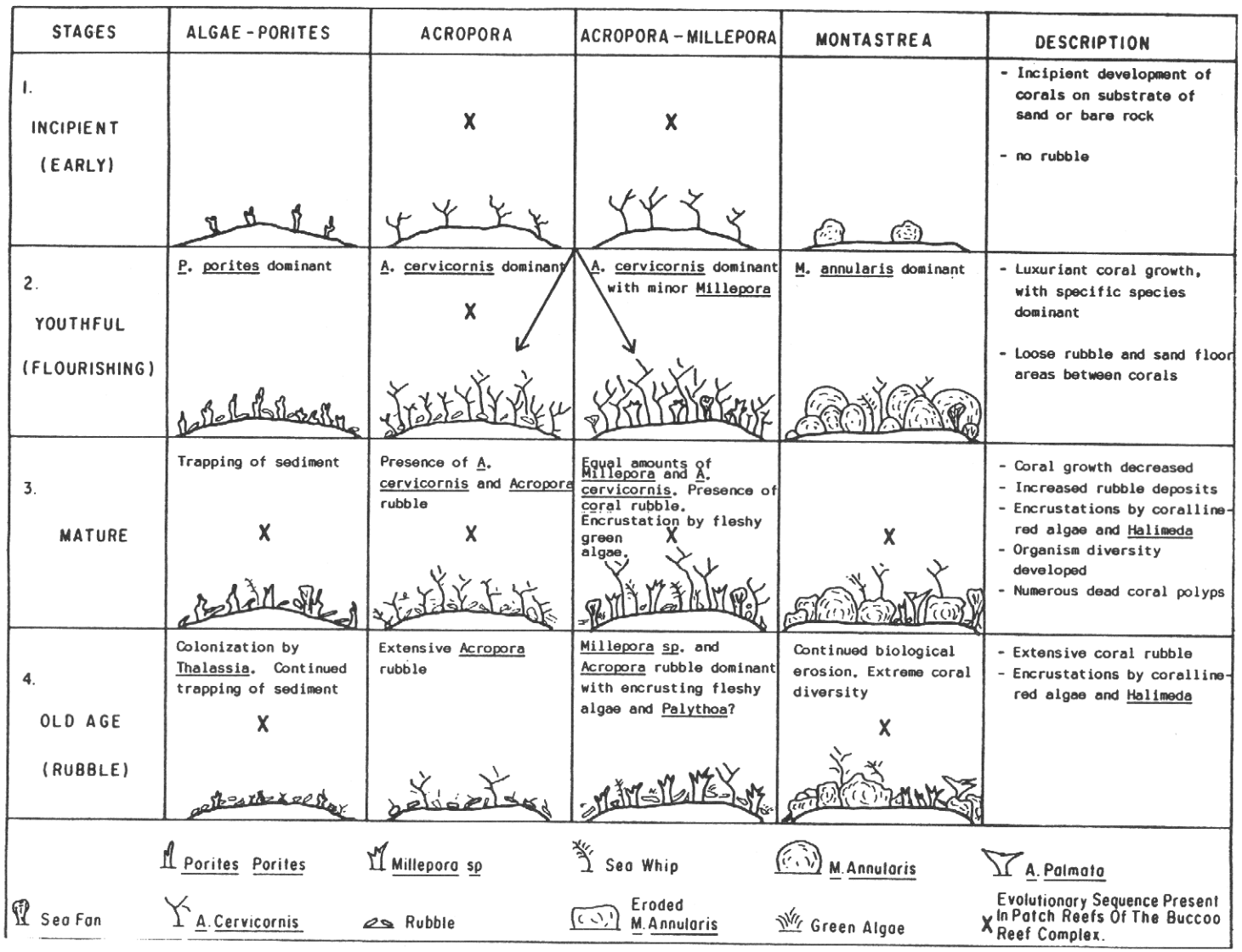


Fig. 8 - Schematic illustration showing suggested evolutionary sequences of patch reefs in the Buccoo Reef Complex. Zones without x's do not occur at present on the reef.

development are probably controlled by a combination of environmental parameters which include bathymetry, wave exposure, water circulation, salinity and turbidity, and the nature of the substrate.

The Porites coral is extremely adaptable to environmentally-stressed areas. For example, it has the ability to reject sediment much better than other varieties (Hubbard and Pocock, 1972). Therefore Porites coral initially colonized the southern lagoonal areas of Buccoo Reef Complex (Fig. 1) which is shallow and turbid, and exhibits low wave energy and moderate water circulation.

Low salinity levels and influx of terrigenous sediment in southern lagoonal areas, especially after very heavy rainfall probably resulted in the death of Porites coral, and the development of extensive coral rubble. Terrigenous sediment (quartz silt) is still being deposited in these areas, as indicated by the sediment analysis. The trapping of sediment by the coral rubble further retarded the growth of Porites, owing to an unstable sediment substrate and increased levels of turbidity. These factors explain the occurrences of the mature and old age stages of development for the Algae - Porites patch reefs.

Acropora communities are well suited to the shallow, well circulated, moderate wave energy conditions of the central and northern lagoonal areas (Fig. 1).

In the southwestern Reef Lagoon, which experiences low to moderate wave energy conditions, breakage of Acropora branches are not extensive, and the patch reefs are in the youthful stage of development. In northeastern Reef Lagoon, where the Acropora patch reefs are more exposed to the waves, damage to the coral branches are more extensive. This results in the formation of coral rubble and the mature stage of development in these patch reefs.

Owing to the increase in wave height, after passing over the deeper waters of the Blue (Deep) Hole, Millepora communities have colonized and replaced Acropora corals in this area (Fig. 1). This results in the formation of Acropora - Millepora patch reefs. Field studies in the Caribbean (Adey, 1975; Adey and Burke, 1977) have shown that Millepora is very adaptive to moderate and high-energy wave conditions. These conditions also restrict the grazing of ecological communities by fish and other invertebrates, resulting in the occurrence of fleshy green algae in these patch reefs.

Extensive damage to Acropora and Millepora colonies by high wave energy, results in extensive rubble development, hence the occurrence of the mature stage of development for Acropora - Millepora patch reefs.

The massive domal-shaped coral heads of the Montastrea Patch Reef develop in the deeper waters of northern lagoonal areas, adjacent to the Blind Passage and Deep Channel (Fig. 1). Montastrea corals are also adaptive to the lower wave energy and decreased light conditions in this area. Low to moderate wave energy conditions in this area as a result of deeper water conditions do not inhibit grazing by fish and other invertebrates. Therefore the coral heads are subjected to extensive biological erosion, resulting in the toppling of some Montastrea corals, and colonization by other corals on these bare surfaces. This feature of coral erosion by organism grazing, and increased coral diversity defines the mature - old age transitional stage of the Montastrea Patch Reef.

Geographic distribution, ecological characteristics and development stages of the four different patch reef types in the Buccoo Reef Complex are therefore primarily controlled by the degree of wave exposure; and moderately influenced by degree of water circulation and turbidity. Geister (1977) also indicated previously that ecological zonation of Caribbean corals are to some extent dependent on the degree of wave exposure. With respect to the major environmental parameters: wave exposure, degree of water circulation and turbidity, which affect the patch reefs of Buccoo Reef, it can be summarized that:

(1) The Montastrea Patch Reef has developed in low wave energy, low water circulation and high turbidity environment.
(2) The Algae - Porites patch reefs are characterized by an environment of moderate water circulation, low wave energy and high turbidity.
(3) The Acropora patch reefs are located in a low to moderate wave energy, moderate water circulation and low turbidity environment.
(4) The Acropora - Millepora patch reefs occur in an environment characterized by high wave energy, strong water circulation and low to high turibdity.

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REFERENCES

Adey, W.H., The Algal ridges and coral reefs of St. Croix - their structure and Holocene development, Atoll Research Bull. 187, The Smithsonian Institution, Washington D.C., 1975.

Adey, W.H., and Burke, R.B., Holocene bioherms of Lesser Antilles - Geologic control of development, 67-81 in Frost, S.H., Weiss, M.P., and Saunders, J.B., Eds., Reefs and Related Carbonates, Amer. Assoc. Petroleum Geologists, Studies in Geology 4 421, 1977.

Case, J.E., Geologic Framework of the Caribbean, 3-26 in Weaver, J.D., Ed., Geology Geophysics and Resources of the Caribbean, Report of the Caribbean Region and its Resources, Kingston, Jamaica, 17-22 February, 1975, 150, 1975.

Frdyl, P., The geological effect of grazing by parrotfish (Scaridae) on a Barbados coral reef, M.Sc. Thesis, Technical Report 77-3, Dept. of Geological Sciences, McGill University, 136, 1977.

Geister, J., The influence of wave exposure on the ecological zonation of Caribbean coral reefs, Proc.of the 3rd. Int. Coral Reef Symposium, Miami, Florida, 23-29, 1977.

Gilmore, M.D., and Hall, B.R., Life history, growth habits and constructional roles of Acropora cervicornis in the patch reef environment, Jour. Sed. Petrology 46, 18-22, 1976.

Hubbard, J.A.E.B., and Pocock, Y.P., Sediment rejection by Recent scleractinian corals: a key to paleoenvironmental reconstruction, Geol. Rundschau 61, 598-626, 1972.

Kenny, J.S., A preliminary study of Buccoo Reef/ Bon Accord Complex with special reference to development and management, Dept. of Biological Sciences, University of the West Indies, St. Augustine, 123, 1976.

Lang, J., Interspecific aggression by scleractinian corals. 2. Why the race is not only to the swift, Bull. Marine Sci., 23, 260-279, 1973.

Mascle, G., Lajat, D., and Nely, G., Sediments deformation linked to subduction and to argillokinesis in the southern Barbados Ridge from multichannel seismic surveys, Transactions of the 4th Latin Amer. Geol. Congress, Port-of-Spain, 873-882, 1979.

Multer, H.G., Ed., Field guide to some carbonate rock environments, Florida Keys and Western Bahamas, Contribution 40, Dept. of Earth Sciences, Farleigh Dickinson University, New Jersey, 175, 1975.

Multer, H.G., and Zankl, H., Distribution, structure and origin of Holocene patch reefs in the West Indies, Proc. of the 5th. Int. Coral Reef Congress 3, Tahiti, 227-228, 1985.

Scatterday, J.W., Low-water emergence of Caribbean reefs and effect of exposure on coral diversity - observations off Bonaire, Netherlands, Antilles, 155-169 in Frost, S.H., Weiss, M.P., and Saunders, J.B., Eds, Reefs and Related Carbonates, Amer. Assoc. Petroleum Geologists, Studies in Geology 4, 421, 1977.

Turmel, R.J., and Swanson, R.G., The development of Rodriguez Bank, a Holocene mudbank in the Florida reef tract, Jour. Sed. Petrology, 497-518, 1976.

Wallace, R.J., and Schafersman, D., Patch-reef ecology and sedimentology of Glovers Reef Atoll, Belize 37-52 in Frost, S.H., Weiss, M.P., and Saunders, J.B., Eds., Reefs and Related Carbonate, Amer. Assoc. Petroleum Geologists, Studies in Geology 4, 421, 1977.